Analysis of a Fall Detection Radar placed on the Ceiling and Wall

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***Abstract* — Fall incidents are considered one of the most dangerous hazards for elderly people. In this regard, radar techniques can be used to develop a long-term fall detector system in home environment. The key relies on measuring and assessing the different changes in speed experienced during a fall and a normal movement. In this paper, the accuracy of a fall detector based on Doppler radar is analyzed comparing speed measurements produced by human subjects during fall incidents, with the radar fixed to the wall and to the ceiling, respectively. Experimental results demonstrate a higher success rate in detecting fall events when performing measurements with the radar fixed to the ceiling.**

Index Terms — Contactless, Doppler, fall detection, health monitoring, movement classification, radar remote sensing, speed measurements.

I. Introduction

Health monitoring is becoming an important topic attracting the attention of many researchers worldwide [1]. In this regard, radar techniques have been investigated aiming at contactless health monitoring for in-door environment [2]. More precisely, in the last two decades, the attention has been focused mainly on contactless vital sign monitoring. In fact, the mechanical movements of heart and chest (lungs) can be detected by adopting radar techniques and in this way heart beat and respiration rate can be measured [3]-[5].

Next to this, radar technologies can be also used to detect fall emergencies in home environment. In fact, due to the Doppler effect, the mechanical movements of the human body cause changes in frequency of the wave reflected from the person, and in this motion speed can be measured [6]-[8]. The different changes of speed can be used to develop an automatic fall detector in order to distinguish fall incidents from daily normal movements (i.e., walking, sitting down, standing up, random movements) [9], [10].

Compared to previous works, which investigated only one fall direction and sensor position, this paper analyzes the effect of the radar positioning on the detection performance under various fall orientations.

The experimental set-up is briefly introduced in Section II, while the experimental results are described in Section III.

II. Experimental Set-up

The health monitoring system used in this work was already described by the authors in [9]. It consists of a sensor, combining radar, computational, and wireless communication capabilities, and a base station for data processing (Fig. 1). The sensor integrates a radar module, a Zigbee module, and a microcontroller, while the base station consists of a Zigbee module, a microcontroller, and a laptop.

A Continuous Wave (CW) waveform at 5.8 GHz is generated and used to detect, exploiting the Doppler effect, the speed signals produced by human volunteers during mimicked fall incidents. The resulting baseband signals are digitized and transmitted to the base station where the data is stored and processed.

A movement classification based on a Least Squares Support Vector Machines (LS-SVM) approach combined with Global Alignment (GA) kernel [10] is applied to analyze the digitized baseband speed signals in order to distinguish falls from normal movements. The technique aims at assessing the changes in speed experienced during a fall or a normal movement. In fact, during a normal movement, the Doppler signal experiences a controlled movement, as opposed to a fall event, where the speed increases continuously until the moment when the person reaches the ground and then his/her movement stops abruptly.

The algorithm consists of two stages of data analysis, namely the training phase and the testing phase. Both phases use the digitized speed signals as input. In the first phase, a model is created containing signals related to fall events and normal movements, that is used to discriminate the monitoring signals in the testing stage.

For more details regarding the health monitoring system and the data processing technique, we refer the reader to [9] and [10], respectively.

III. Experimental Results

The experimental measurements were performed with three human subjects in a lab with the radar sensor fixed to either the wall or the ceiling (Fig. 2). More precisely, the first set of measurements was performed with the radar fixed to the wall at height of 1 m and with the subjects at 3 m distance away from the radar sensor. On the contrary, the second set was achieved with the radar sensor fixed to the ceiling at a height of 3 m. In both scenarios, the three volunteers had to mimic frontal soft falls trying to produce, within the line of sight (LoS) of the antenna, angles between 0 and 360 degrees with step of 30 degrees, as indicated in Fig. 2. For each body orientation, three falls have been mimicked by each volunteer, who was alone in the room during the speed measurements. Subjects 1, 2, and 3 are 1.78 m, 1.78 m, and 1.87 m tall, respectively, while their weights are respectively 74 kg, 95 kg, and 85 kg, enabling the analysis of different fall speeds.

The measured speed signals have been processed with a model estimated on the basis of different types of activities, namely falling, sitting down, standing up, walking, and random movements. More precisely, the model contains 90 activities acquired from one person, who has not participated in the testing phase, of which 60 are normal movements (i.e., walking, sitting down, standing up, random movements) and 30 are fall activities.

Figs. 3a, 3b show the speed signals, measured with the radar fixed to the wall, of a human producing while falling an angle of 0 and 90 degrees, resp., within the antenna's LoS. As can be deduced, the frequency of the signals in Fig. 3a is much higher than Fig. 3b, even if the same person is mimicking similar movements. Moreover, the signals in Fig. 3b have a frequency content lower than the signal plotted in Fig. 3c, corresponding to a walking movement with 0° orientation. These results are expected since the Doppler frequency is proportional to the radial speed of the target, such that, when the movements become more and more perpendicular to the antenna's LoS, the resulted target speeds will produce a lower Doppler frequency and a fall event will be classified as normal movement.

Different results are obtained when the radar is fixed to the ceiling. In fact, signals in Figs. 4a, 4b, corresponding to fall movements producing respectively angles of 0 and 90 degrees within the antenna's LoS, present a similar frequency content that is higher than the frequency content of the walking signal plotted in Fig. 4c.

The experimental results have shown that the sensitivity in detecting fall incidents with the radar fixed to the wall decreases as the human mimicks falls that become more and more perpendicular to the antenna's LoS. In fact, the fall detector was always able to detect falls when the three volunteers produced angles of 0, 30, 150, 180, 210, and 330 degrees within the antenna's LoS, while it never detected falls in the other body orientations (i.e., 60, 90, 120, 240, 270, 300 degrees). This problem was solved fixing the radar to the ceiling. In this case, in fact, the targets will never produce movements that are perpendicular to the antenna's LoS and all the mimicked fall events by the three volunteers were always detected.

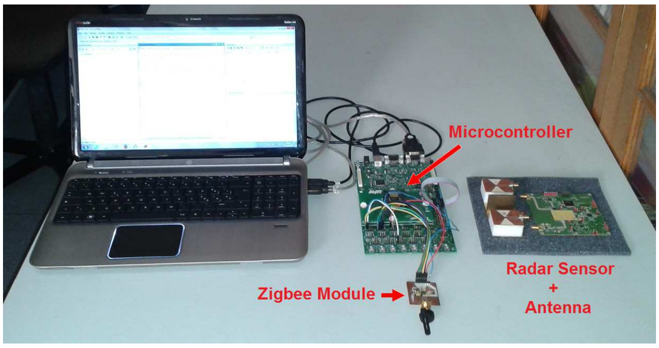

Fig. 1. Developed sensor and base station.

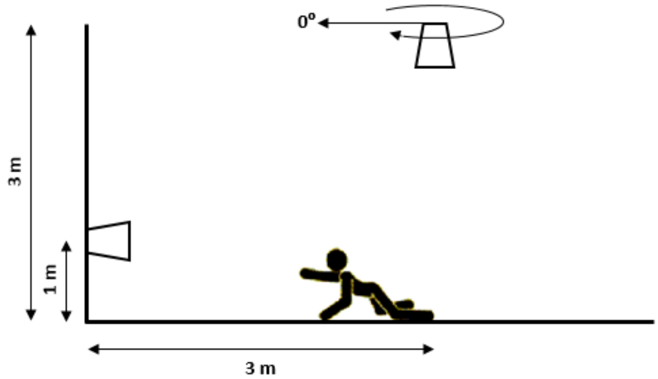

Fig. 2. Measurements set-up.

IV. Conclusion

In this work, the accuracy of a radar-based fall detector has been analyzed performing speed measurements with the radar fixed both to the wall and to the ceiling. Experimental results have shown a success rate of 100% in detecting fall events when the radar is fixed to the ceiling, allowing also to overcome the limitation imposed by the Doppler effect that occurs when the radar is fixed to the wall.

Acknowledgement

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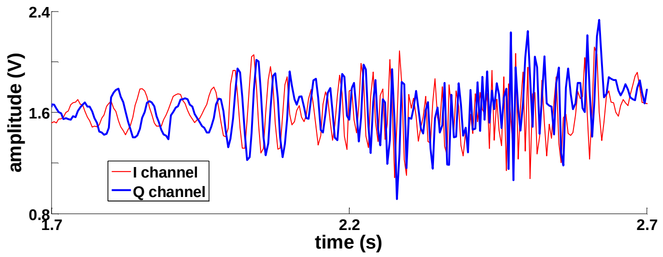
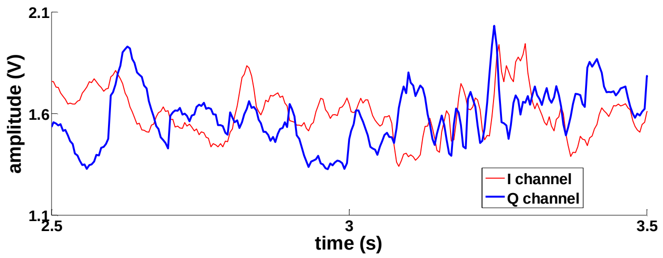
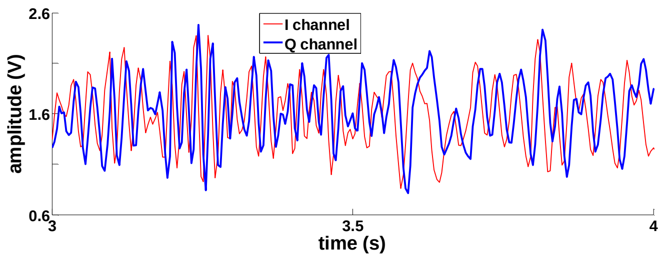


(a)

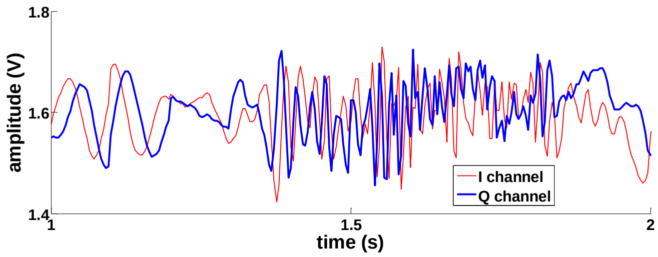


(b)

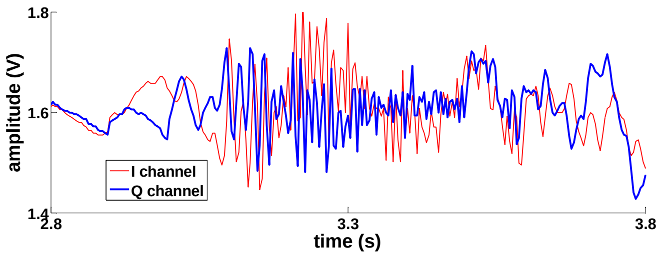


(a)

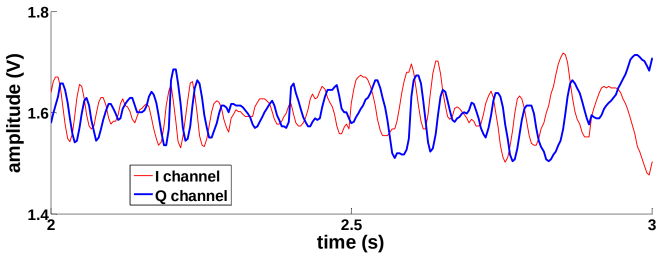
Fig. 3. Speed signals acquired with the radar fixed to the wall. The frequency of the signals is proportional to the radial velocity of the person during the movement. In (a) the subject is falling with 0° orientation, in (b) the volunteer is falling with 90° orientation, while in (c) the person is walking with orientation 0°.



(a)



(b)



(c)

Fig. 4. Speed signals acquired with the radar fixed to the ceiling. The frequency of the signals is proportional to the radial velocity of the person during the movement. In (a) the subject is falling with 0° orientation, in (b) the volunteer is falling with 90° orientation, while in (c) the person is walking with orientation 0°.

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